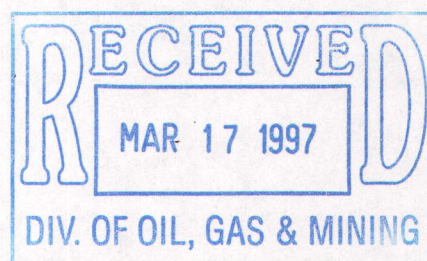# CONTRIBUTIONS TO ECONOMIC GEOLOGY IN UTAH — 1986

By Mark D. Bunnell and Theodore W. Taylor

UTAH GEOLOGICAL AND MINERAL SURVEY
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UTAH GEOLOGICAL AND MINERAL SURVEY

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INTRODUCTION

By Alex C. Keith

The support of graduate level geologic investigations within the State of Utah is an objective of the individual programs within the Utah Geological and Mineral Survey (UGMS). This support is done on a contract basis and includes money and various forms of equipment and tools. Both of the authors in this Special Studies publication were supported by the UGMS through such programs. Mark Bunnell was contracted through the coal geology program under the supervision of Archie Smith. Theodore Taylor was contracted through the metals program under the supervision of Hellmut Doelling.

Support for these students is initially based on a $1,500 grant and the publication of their final report. Other assistance is offered to the students in the form of advice, field checking their work, and air photos and base maps. The student has completed his obligation to the UGMS when a final acceptable product has been delivered and the work has been field checked by UGMS staff members and other invited scientists.

The theses are then edited by the contract supervisor, other UGMS personnel, and selected non-UGMS professionals. The outside review of M. Bunnell's thesis was done by Prof. V. J. Hucka of the University of Utah Mining Engineering Dept. and Rick Smith, Engineering Geologist, Utah Division of Oil, Gas, and Mining. The comments which they provided were valuable in creating the final published report.

PETROLOGY AND GEOCHEMISTRY OF THE
O.K. COPPER-MOLYBDENUM DEPOSIT, BEAVER COUNTY, UTAH

By Theodore W. Taylor [1]

ABSTRACT

The O.K. deposit, located in the Beaver Lake Mountains of southwestern Utah, is a hydrothermal copper-molybdenum deposit hosted by a calc-alkalic quartz monzonite intrusion of Oligocene age. Primary ore minerals, chalcopyrite, molybdenite, and minor pyrite are concentrated in a pipe about 100 feet (30 m) in diameter composed of coarsely crystalline quartz. Minor occurrences of vein, disseminated, and fracture-filling mineralization are also present. Mining of high-grade ore pockets within the pipe prior to 1902 produced 1145 tons of ore averaging 40 percent copper, 7.5 oz/ton silver, and .18 oz/ton gold. Total production from the mine through 1974 was about 650,000 tons of ore containing about 7716 short tons of copper. No molybdenum grades are available.

Hydrothermal alteration of quartz monzonite around the mineralized pipe is represented by a series of concentric, nested alteration zones containing mineral assemblages similar to those found in porphyry stock work deposits. Silicic, quartz-sericite (phyllic), argillic, and propylitic alteration zones were identified, both mineralogically and geochemically.

Mineralization is interpreted to be most closely related to the low fluorine, plutonic, calc-alkalic type of stockwork copper-molybdenum deposits with many characteristics of magmatic-hydrothermal breccia pipes. Possible genetic models for the deposit are presented and exploration possibilities discussed.

INTRODUCTION

The O.K. deposit is a small copper- and molybdenum-bearing body of massive quartz hosted by quartz monzonite. It is located in the southern Beaver Lake Mountains, approximately 10 miles (16 km) northwest of Milford, Utah (figure 1), and is bounded by the San Francisco Mountains to the west, the Milford Basin to the south, the Rocky Range to the southeast, and the Beaver River Valley to the east and north. Access is provided by numerous dirt roads from Utah Highway 21 near Milford, Utah.

Discovery of the O.K. deposit was made in the 1870s and mining began in 1900 (Butler, 1913). Production was intermittent between 1900 and 1975. Early production, from 1900 to 1907, exploited a high-grade pod of copper-molybdenum ore by underground methods. Early production, prior to 1902, consisted of 1145 tons of ore averaging 40 percent copper, 7.5 oz/ton silver, and .18 oz/ton gold (Butler, 1913). Underground workings totalled approximately 4500 feet (1371 m) in length and consisted of a shaft, an incline, and three levels at 200, 300, and 400 feet (61, 91, 122 m) (Butler, 1913). Exploration in the area resumed in the 1950s when the Bear Creek Mining Company became interested in the area and conducted a drilling program. In 1968, open-pit mining began at the O.K. deposit after a merger between the American Mining Company and the West Toledo Mining Company. Ore was treated by acid leach and cementation. In 1970, Shield's Development Company operated the O.K. Mine and in 1971 Essex International, Inc. took over operations. Essex operated the mine until it closed in 1973. Steven and Morris (1984) report that about 7 million Kg of copper and minor gold and silver were produced from the mine. Approximately 7,000 short tons of copper (635,000 tons of ore) were produced by open pit mining after 1970.

Early investigations in the area were conducted by B.S. Butler in the early 1900s (Butler, 1913; Butler, 1914; Butler and others, 1920). A study of the geology and ore deposits of the Beaver Lake Mountains was made by Barosh (Barosh, 1960). Geologic mapping of the Milford 15′ quadrangle, which includes the O.K. deposit, was completed in 1979 (Lemmon and Morris, 1979) and the adjacent Beaver quadrangle was done in 1984 (Lemmon and Morris, 1984). A mineral resource potential study of the Richfield 1° x 2° quadrangle (Steven and Morris, 1984) was completed which provides a regional volcano-tectonic framework from which the O.K. deposit may be viewed.

The present study was undertaken to gain an understanding of the processes of mineralization and alteration which produced the O.K. deposit. Field work consisted of limited mine mapping and sample collection. A total of 47 samples from a .3 acre (1200 m²) were collected, encompassing both the O.K. and adjacent Beaver-Harrison deposits. Plate 1 shows sample locations in and adjacent to the O.K. pit. Drill cuttings
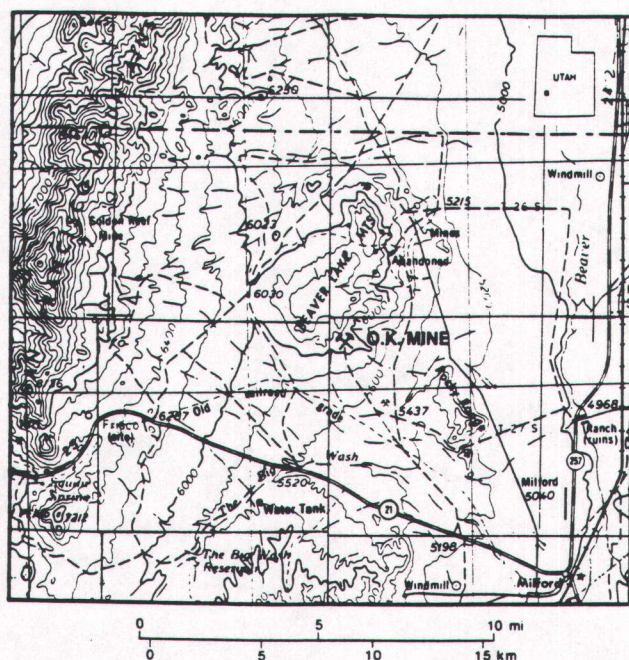
Figure 1. Location map of the O.K. Mine and vicinity.

from holes in the O.K. Mine were made available for this study. Drill samples were collected from horizontal holes at the 200-foot (61-m) level of the mine and are shown in figure 6. As an example of the sample numbering system, the sample number 20-110 designates that it was collected 110 feet (33.5 m) along drill hole no. 20. A total of 61 thin and polished sections were made from the collected samples.

This study was based largely on laboratory studies of samples collected from the O.K. Mine area. Methods used include petrography, x-ray fluorescence, electron microprobe analysis, x-ray diffraction, and fluid inclusion studies.

GEOLOGY AND STRUCTURE OF THE BEAVER LAKE MOUNTAINS

A geologic map of the Beaver Lake Mountains is shown in figure 2 (Barosh, 1960). In general, Paleozoic sedimentary rocks are dominant in the northern part of the range whereas Tertiary volcanic and intrusive rocks comprise the southern two-thirds of the range. Paleozoic rocks, dominantly dolomite and limestone, range in age from Cambrian through Mississippian. The Beaver Lake thrust fault is exposed at the northernmost edge of the range with Cambrian rocks of the upper plate lying to the north (Lemmon and Morris, 1984). Ordovician through Mississippian sedimentary rocks comprise the lower plate of the thrust south of the surface trace. Intrusive rocks of quartz monzonitic to granodioritic composition, of the calc-alkalic magma series, occur as two stocks, one centered near Smith Spring in the northern portion of the range, and the other, informally termed the O.K. stock (Lemmon and others, 1973), in the southern part of the range. The O.K. stock has been dated by K/Ar methods at 28.4 Ma (Lemmon and others, 1973).

Intrusive rocks are locally cut by swarms of aplite dikes. Volcanic rocks, which comprise broad areas in the central part of the range, are correlated with the Horn Silver andesite of Stringham and have been dated at 30.8 and 34.1 Ma (Lemmon and others, 1973). Flows range in composition from andesite to quartz latite with dacite being dominant. Sericitization and silicification of volcanic units are common along intrusive contacts.

A regional account of structural features, including the Beaver Lake Mountains area, was presented by Schmoker (1972). Using geophysical data, Schmoker concluded that the San Francisco, Beaver Lake, Rocky, and Star Ranges comprise a region underlain by a large, tabular Tertiary intrusion. From Schmoker's work, one may infer that the various stocks present in the Beaver Lake Mountains are cupolas of this large, deep-seated composite batholith.

DESCRIPTION OF THE O.K. MINE

The O.K. deposit is hosted entirely by equigranular quartz monzonite of the O.K. stock. Except along fractures, the stock is relatively free of alteration (Butler, 1913). However, alteration has been extensive in proximity to the O.K. deposit. Petrographic features of the mineralization are presented in a later section. At least three dikes cut the quartz monzonite host in the mine area, two of which are defined in this study and an aplite dike described by Butler from the O.K mine workings.

A fissure system striking N80°W (figure 3) was noted by Butler (1913) and Barosh (1960) and appears to be coincident with a mineralized quartz-rich pipe in the mine area (figure 3). This fissure system is represented in the field by slickensided fault surfaces noted at several locations along the ramp of the O.K. pit. Strike and dip measurements of these surfaces reflect the general east-west trend. Faults are shown on the mine map in figure 6.

Primary ore minerals present in the O.K. deposit are chalcopyrite, molybdenite, and associated minor pyrite. High-grade mineralization was concentrated at the 200-foot (61-m) level of the mine in a pod with dimensions of 70 by 35 by 46 feet (21 x 11 x 14 m), located adjacent to the quartz-rich pipe (figure 4, Butler, 1913). Smaller areas of higher grade ore lie along the margin of the pipe (Butler, 1913). Disseminated chalcopyrite-molybdenite mineralization occurs as small veins of quartz and sulfides and as disseminated grains within altered quartz monzonite. Butler (1913) noted that disseminated mineralization lies within 50 feet (15 m) of the pipe and that disseminated ore values are generally highest in the veined zone adjacent to the pipe. Butler also observed disseminated mineralization in a relatively unaltered aplite dike at the base of the workings.

Secondary ore minerals observed in the field include malachite, azurite, chrysocolla, limonite, covellite, and cuprite. Secondary oxides and carbonates are generally absent beneath the 200-foot (61-m) level of the mine (Butler, 1913). A zone of sulfide enrichment underlies the oxidized zone in which covellite and chalcocite partly replace primary chalcopyrite and pyrite (Butler, 1913). Secondary alteration of molybdenite to powellite has been reported (Butler, 1913).
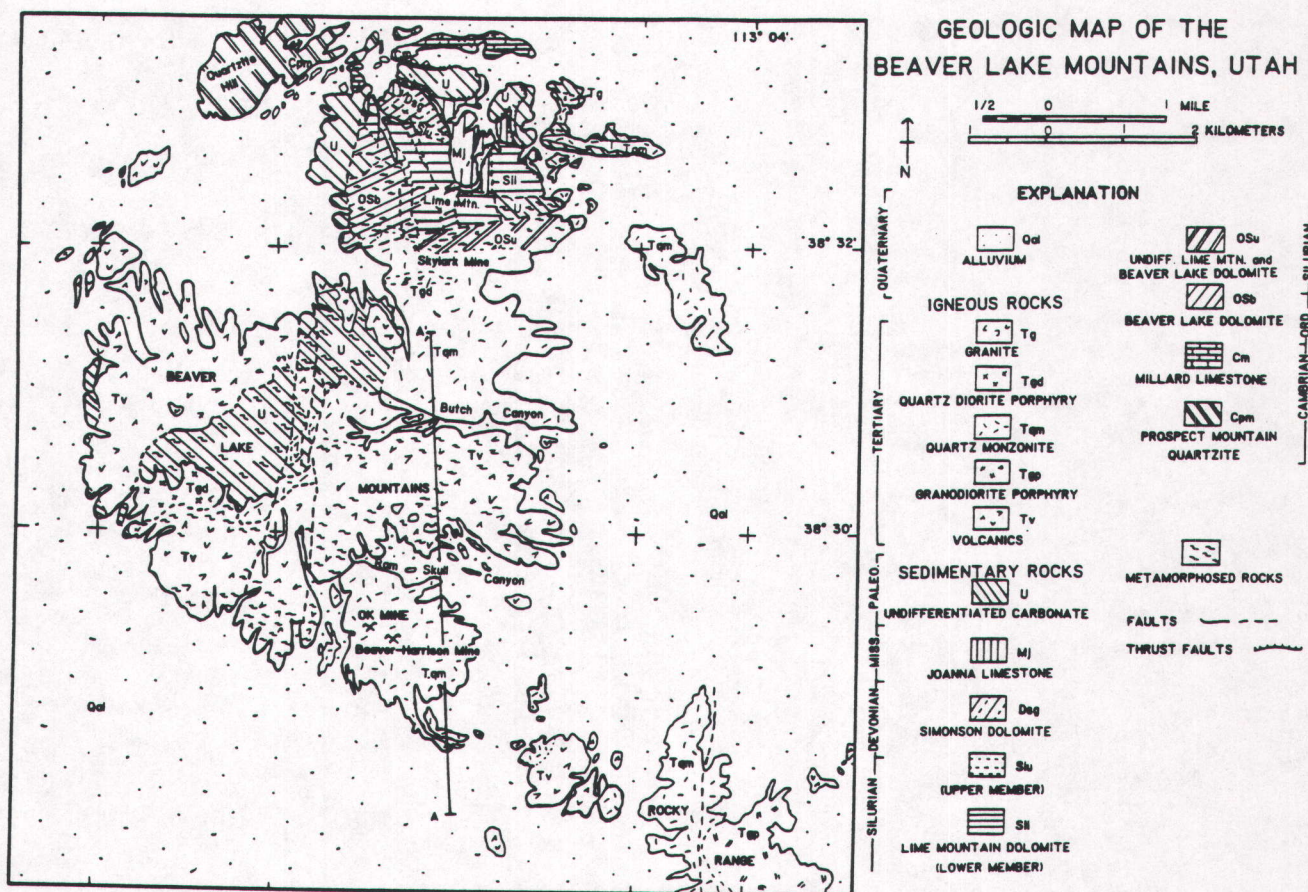
Figure 2. Geologic map of the Beaver Lake Mountains, Utah (from Barosh, 1960).

Gangue minerals present include quartz and sericite. Within the pipe the dominant mineral is very coarse, pegmatitic quartz. Cavities lined with coarse quartz crystals are common. Butler (1913) describes highly altered clasts of quartz monzonite toward the margin of the pipe, quartz monzonite being altered to quartz and sericite. Other minerals present in minor amounts in or adjacent to the deposit include kaolinite, chlorite, rutile, and rare tourmaline (Butler, 1913; this study).

Steven and Morris (1984) briefly described the O.K. deposit as "a nearly vertical pipe-like mass of breccia 60-65 m across in which pyrite, chalcopyrite, and molybdenite are disseminated through crackled quartz monzonite surrounding a silicified core." H.T. Morris (personal communication, 1985) mentioned having seen breccia textures at the center of the pipe-like body.

The Beaver-Harrison mine, located about 2000 feet (600 m) southeast of the O.K. deposit, also contains a coarse-grained quartz mass exposed at the top of the shaft. Tourmaline was noted along quartz grain boundaries during this study.

DESCRIPTIVE PETROGRAPHY OF THE O.K. MINE ROCKS
Compositional Variations

The O.K. stock is dominantly quartz monzonitic to granodioritic in composition. Sample locations where these compositions were found include OC-4, OC-5, OC-7, OC-9, IC-4 to IC-9, and IC-11 (see plate 1). Amphibole, biotite, and chlorite together constitute approximately 15 percent of the rock. Amphibole is the dominant mafic mineral and constitutes 8 to 12 percent, and biotite 5 to 10 percent. Chlorite occurs in variable amounts depending on the degree of alteration. Quartz typically constitutes 10 to 22 percent and feldspar comprises roughly 65 percent of the rock with the abundance of plagioclase being either equal to or slightly greater than potassium-feldspar. Accessory minerals include magnetite, sphene, and apatite. Calcite and epidote occur in small amounts as alteration products of plagioclase and amphibole. Accessory and alteration minerals constitute as much as 5 percent of the rock.

Samples IC-2, IC-10, OC-3, OC-6A, OC-6C, OC-8, BD-1, R-8.3B, R-8.4, R-8.6B, R-8.8A, 20-110, 27-5, and 33-30 have a more granitic composition. Biotite, either partially or entirely altered to chlorite, is the dominant ferromagnesian mineral and constitutes 5 to 10 percent of the rock. The abundance of alkali feldspar, which appears to be greater than that of plagioclase, is difficult to assess due to extensive alteration of these samples.

Samples located between locations R-3 and R-8.2B contain even greater amounts of potassium feldspar relative to plagioclase, and quartz is more abundant. Biotite, partially altered to
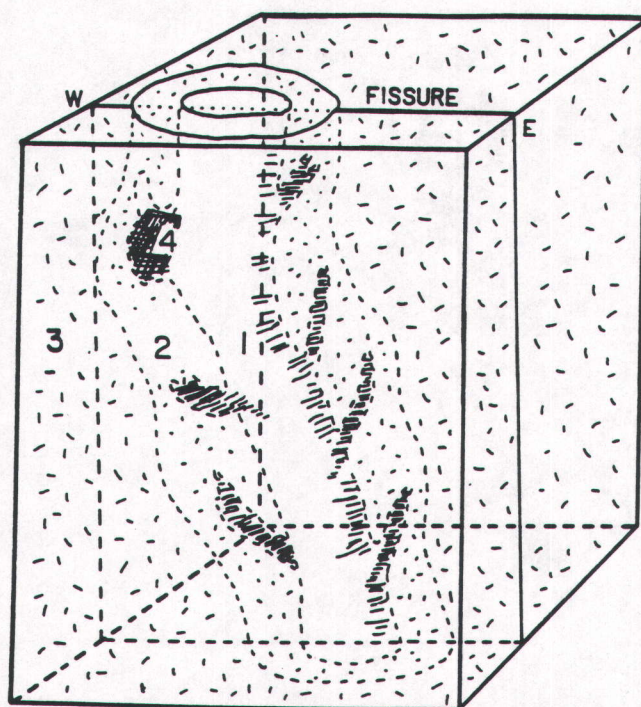
Figure 3. Generalized stereogram showing the relation of pegmatitic quartz and mineralized quartz monzonite in the O.K. Mine (from Butler and others, 1920). 1) Pipe of pegmatitic quartz, 2) altered quartz monzonite, 3) quartz monzonite, 4) high-grate ore.

chlorite, is again the only mafic mineral, but constitutes 10 to 15 percent of the rock.

Textural Variations

Holocrystalline and phaneritic textures of the O.K. stock are dominant with a fabric ranging from equigranular to seriate porphyritic. Plagioclase is euhedral to subhedral, whereas potassium feldspar is typically subhedral. These minerals range in size from coarse-grained phenocrysts (greater than 5 mm) to that of the groundmass (less than 1 mm). Groundmass consists of quartz, amphibole, biotite, and chlorite. Magnetite is fine grained, euhedral, and almost always found in granular aggregates with amphibole or biotite. Sphene is fine grained and anhedral, but commonly has sharp, distinct grain boundaries and fills the interstices between preexisting minerals such as feldspar. It usually occurs in groups of anhedral grains that are optically continuous, indicating that it is a late-forming, primary mineral. Calcite and epidote are very fine grained, anhedral, and usually associated with plagioclase or amphibole.

An interesting textural variation of the quartz monzonite lies between sample locations R-3 and R-8.2B. Occurring within this interval is the more granitic rock described above which has a poikilitic texture. Potassium feldspar occurs as relatively unaltered coarse-grained anhedral grains which completely engulf grains of moderately altered plagioclase, biotite, and/or quartz. Quartz occurs as coarse anhedral

grains or as granophyric intergrowths with potassium feldspar. The eastern margin of this poikilitic body appears to be gradational with equigranular rocks, a texture change suggesting that the poikilitic body developed as a large-stage crystallization product rather than being a later dike.

·A post-alteration dike was tentatively identified which strikes NNE across the pit. The dike is fine to medium grained and equigranular with interstitial quartz in domains of optical continuity. Samples IC-4 and R-8 were collected from the dike (plate 1).

Another dike was tentatively identified and is represented by samples IC-2, OC-8, and BD-1 (plate 1). Groundmass in these samples is much finer grained than the quartz monzonite and imparts a more distinctly porphyritic appearance. This finer grained groundmass, mainly quartz with minor potassium feldspar, has a very distinctive, interlocking "jigsaw" texture.

Silicate Rock Alteration

In the following discussion, terminology used for hydrothermal alteration assemblages is taken from Mutschler, Wright, Luddington, and Abbot (1981) and Lowell and Guilbert (1970). These systems were adopted primarily for use in granitic molybdenite systems and porphyry copper systems, respectively. Figure 4 diagramatically depicts hydrothermal alteration zonation at the O.K. deposit and should be referred to during the following discussion.

It is apparent from field and petrographic examination that the center of the alteration/mineralization system of the O.K. deposit is the coarse-grained quartz-rich pipe. This was documented by Butler (1913) who collected most of his information from underground workings. The silicic assemblage is interpreted to have originated by intense replacement of quartz monzonite breccia and by interstitial quartz precipitation.

Immediately surrounding the silicic core are highly seriticized and silicified rocks. Examples of this alteration include samples R-10.4, R-10.3, R-10.2, R-10.1, and R-9.1. This alteration zone may be termed the quartz-sericite alteration assemblage (Mutschler and others, 1981), or the phyllic zone of Lowell and Guilbert (1970). Primary feldspars have been entirely replaced by fine-grained mats of sericite. Quartz has been added to the rock and a minor amount of chlorite is present. Quartz occurs as both dispersed grains among sericite masses and as coarser grained vein material. Sample R-9.1, which is about 30 feet (90 m) from the silicic core, represents the maximum lateral extent of this alteration.

Away from the silicic core and up the pit ramp, the intensity of feldspar alteration decreases sharply as evidenced by sample R-9. Kaolinite was found (by x-ray diffraction) to be the major alteration product of feldspars starting at locality R-9 and continuing westward up the ramp. This kaolinite-bearing alteration assemblage is indicative of the argillic alteration assemblage.

A gradational boundary between argillic and propylitic alteration is present in the mine area. Following convention, the first appearance of secondary calcite and/or epidote associated with a feldspar or amphibole was chosen as the
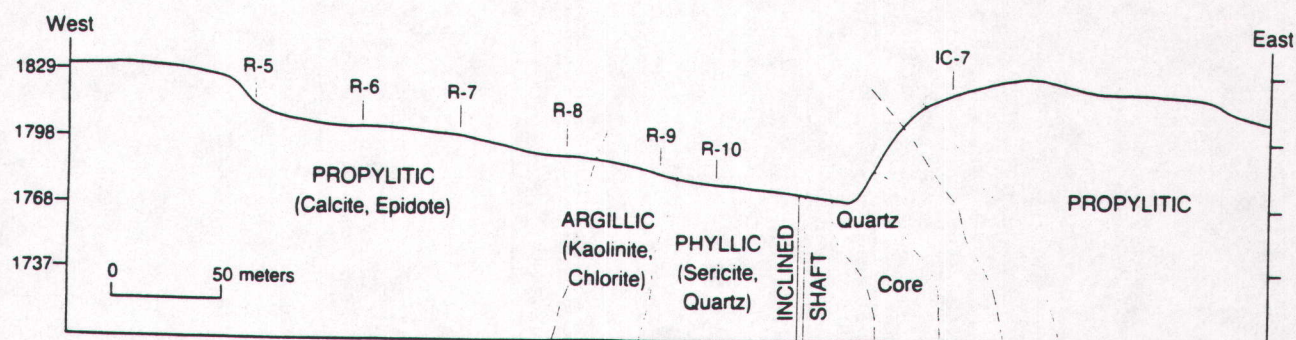
Figure 4. Diagrammatic cross section showing spatial relationships of the phyllic, argyllic and propylitic alteration zones.

boundary between the zones. This occurs in sample R-8.4. Argillic alteration, then, occurs over a roughly 98-foot (30-m) wide interval between locations R-9 and R-8.4

Rocks of the OC and IC sample series have been propylitized, an alteration zone that was also documented by Barosh (1960). The commonly observed mineral association of amphibole (probably actinolite), chlorite, magnetite plus or minus sphene, epidote, calcite, and biotite is probably an alteration product of either original hornblende or pyroxene. In fact, this association most likely represents two stages of alteration. The original mineral was probably altered to actinolite and magnetite, with or without calcite and epidote. Then a second and less intense stage of alteration may have produced biotite, chlorite, and sphene from actinolite.

The final type of alteration to be discussed is that found in samples R-8.8B, R-8.7, R-5A, and R4. In hand specimen, these rocks have a greenish color due to evenly distributed, very fine-grained patches of chlorite. Feldspars have been altered to very fine-grained sericite. It is notable that samples R-8.8B and R-8.7 contain two of the three observed occurrences of disseminated chalcopyrite at the O.K. deposit. This alteration is restricted to narrow bands (several cm wide) straddling fractures and may represent a late, less intense stage of alteration.

Hydrothermal alteration at the Beaver-Harrison Mine is similar to that at the O.K. Mine. A coarse-grained quartz mass is located near the top of the shaft Beaver-Harrison. Sericite and kaolinite were noted in other samples. Insufficient sampling was done here to identify alteration zonation.

Copper-Molybdenum Mineralization

Primary sulfide mineralization was found to be relatively simple, consisting of chalcopyrite, molybdenite, and rare pyrite. Mineralization is spatially associated with the coarse-grained silicic core. Distribution of mineralization was discussed previously.

Few samples of ore material were collected in the field. Samples R-10.1, R-10.2, R-8.6A, and T-1 contain chalcopyrite-bearing quartz veins. BD-1 contains chalcopyrite along a joint surface with minor quartz. Samples T-2 and T-3 contain molybdenite disseminated in a quartz and feldspar gangue. Other pieces of coarse-grained quartz debris contain large grains and lenses of both chalcopyrite and molybdenite. Finely disseminated chalcopyrite was observed in minor

amounts in samples R-8.8B, R-8.7, and R-8A of the O.K. deposit and in samples OC-6A and OC-6C of the Beaver-Harrison deposit. The only observed occurrence of pyrite at the O.K. deposit was along a mineralized joint surface at site BD-1.

In thin section and in hand specimen, sample T-2 has an aplitic texture and contains only medium- to fine-grained quartz and potassium feldspar with disseminated molybdenite. In hand specimen, this aplitic rock exhibits a sharp contact with altered quartz monzonite, and it may represent the mineralized aplite dike reported by Butler (1913) and found below the 400-foot (122-m) level of the O.K. Mine.

Secondary Effects

Oxidation processes at the O.K. Mine, enhanced by the arid climate and abundant fractures and joints, have affected primary ore minerals, particularly chalcopyrite. A zone of supergene sulfide enrichment, which occurs at or below the existing water table, was noted by Butler (1913) to contain secondary covellite and chalcocite but was not observed in this study.

In almost all of the samples of chalcopyrite collected, thin veinlets of rusty-brown limonite, and less commonly malachite, occur as oxidation products within the chalcopyrite. In polished section, cuprite and covellite were found associated with these limonite veins. This particular textural and mineralogical association is described by Ramdohr (1980) as a common oxidation phenomenon in chalcopyrite and occurs in environments where pyrite is lacking (Jensen and Bateman, 1979; Titley, 1982).

MAJOR ELEMENT GEOCHEMISTRY

Geochemical data were collected so that trends in elemental concentrations could be delineated. Drill cuttings from horizontal holes at the 200-foot (61-m) level were used for whole-rock analysis. Samples were spaced at intervals of either 10 or 15 feet (3 or 15 m) along nine different holes and locations are given in figure 6. Samples collected in the field were also analyzed.

Geochemical data were acquired by x-ray fluorescence spectroscopy (XRF). Relative abundances of ten major elements, namely silicon, aluminum, iron, magnesium, potassium, sodium, calcium, titanium, phosphorus, and

managanese, were determined. Accuracy of elemental abundances are within two percent of the number listed, except silica which may vary up to four percent.

Very distinct trends are apparent in the distribution of potassium, sodium, calcium, and silicon. Trends in the other elements are either very weak or absent, and the copper distribution is especially erratic.

Distributions of potassium, sodium, calcium, and silicon abundances show an elongated, oval pattern which roughly parallels the long, east-west axis of the underground workings and present open pit. A strong, well-defined potassium high is found at the center of the mine area, with concentrations decreasing away from the workings out into the stock. The highest concentrations of potassium are adjacent to the silicic core. Silica concentrations coincide with the potassium concentrations, being high at the center of the mine area and decreasing outward. Sodium and calcium also have well-defined patterns but are inversely related to the potassium and silicon concentrations. These two elements are low at the center of the mine area and increase outward into the wall rock.

Enrichment in potassium, and corresponding depletion in sodium and calcium, reflects an increase in the amount of potassium feldspar relative to plagioclase and/or the development of sericite at the expense of feldspar minerals. By petrographic analysis, this high potassium concentration at the O.K. Mine corresponds to the quartz-sericite or phyllic assemblage alteration. Calcium, which was leached from the inner zones of alteration, was probably precipitated in the outer fringe of the system in the propylitic zone of alteration.

Water content of the rocks was determined approximately as the loss in weight during fusion (LOI) even though very minor amounts of sodium, sulfur, and carbon dioxide may also have been lost. Water content may be considered to be an indicator of the relative intensity of hydrothermal alteration. Rocks with the highest water content parallel the fault system shown in figure 6.

Based on the above geochemical observations, one may make some interpretations about the nature of the hydrothermal solutions. Given the enrichment in silicon and potassium in the center of the mine area, it may be inferred that the hydrothermal solutions were enriched in both potassium and silicon. Also, the abundance patterns of potassium, silicon, calcium, sodium, and water are all centered on, distributed symmetrically about, and elongate parallel to the east-west fracture zone mapped by Butler (1913) and shown on figure 6. More specifically, the patterns are centered on the silicic pipe. Thus, one may infer that the fracture zone, especially the silicic pipe area, served as the channelway through which solutions were being introduced to the O.K. Mine area.

FLUID INCLUSIONS

Fluid inclusions from samples R-10.1, R-10.2, R-8.6A, T-5, and T-6 of the O.K. deposit and OC-6D of the Beaver-Harrison deposit were examined. Primary fluid inclusions were divided into four types based on data from porphyry copper deposits. Nash (1976) suggested that four types of

inclusions are common in the porphyry environments. These are: 1) Moderate Salinity (Type 1); 2) Gas-rich (Type 2); Halite-bearing (Type 3); and 4) CO_2-rich (Type 4). The reader is referred to a paper by Nash (1976) for the characteristics and significance of each type. Samples from the O.K. Mine area contained dominantly secondary inclusions with relatively rare primary inclusions.

Qualitative Results

All samples contain inclusions of the Type 1 variety. Each of these inclusions contain a gas bubble which occupies 20 to 30 percent of the inclusion volume. Sample R-10.1 contains opaque daughter minerals in secondary inclusions which are probably magnetite, chalcopyrite, or pyrite. The presence of these ore minerals in secondary inclusions is significant because it may indicate that either primary magmatic fluids were not responsible for mineralization or, more likely, that there was more than one episode of mineralization.

Gas-rich inclusions (Type 2) are present in R-10.1, T-5, T-6, and OC-6D. The co-existence of these inclusions with liquid-rich Type 1 inclusions suggests that the liquids were boiling at the time of entrapment (Nash, 1976; Roedder, 1979). Halite-bearing inclusions (Type 3) are present in samples OC-6D and R-10.1 associated with gas-rich inclusions. Halite-bearing inclusions are also common in porphyry copper deposits (Nash, 1976). The presence of halite is also significant in that it indicates that the fluids were saline and that the chloride ion was present in abundance.

Quantitative Results

Using the fluid inclusion stage, the temperature at which ore-bearing fluids were trapped can be determined. To be able to draw statistically sound conclusions from filling temperature data, tens of inclusions from each sample should be analyzed. Unfortunately, primary inclusions were quite rare in the samples used in this study. Also, the presence of gas-rich inclusions invalidates filling temperature readings for reasons discussed by Roedder (1979).

After these considerations, reliable filling temperatures for only four primary inclusions were obtained and are listed in table 1. The temperatures ranged from roughly 250° to 350°C, within the range for hydrothermal fluids in a typical porphyry copper deposit (Nash, 1976).

Filling temperatures for secondary inclusions were determined to be in the range of 140° to 190°C. Their significance with respect to the overall ore-forming process is not certain, but they may suggest the existence of more than one episode of fluid transport and may be responsible in part for the mineralization at the O.K. Mine as evidenced by the daughter minerals in R-10.1.

DISCUSSION

A review of many deposit-type models has shown that the O.K. deposit cannot be uniquely classified. Three deposition models are applicable; porphyry copper, stockwork molybdenum, and magmatic-hydrothermal breccia pipe deposits. Comparisons between the O.K. Mine and each of these models will be made.

Table 1. Tabulation of quantitative fluid inclusion data.

Sample	Inclusion Description	Filling Temperature (°C)
R-10.1	Primary; Gas-rich, halite-bearing, and moderate salinity.	>350
	Secondary; Oriented with others along seams, contain opaque daughter minerals.	183.3
	Secondary; Oriented.	186.4
R-10.2	Primary; Moderate salinity.	298.2
	Primary; Moderate salinity.	274.9
	Secondary; Oriented, relatively small.	192.7
	Secondary; Oriented along seams.	150.1
LR-8.6A	Primary; Moderate salinity.	252.6
	Primary; Moderate salinity, relatively large.	261.3
	Secondary; Oriented along seams.	154.7
T-5	Primary; Gas-rich.	>350
	Secondary; Oriented along seams.	180.5
	Secondary; Oriented along seams.	184.2
T-6	Primary; Moderate salinity, relatively large.	318.6
	Primary; Gas-rich.	>350
	Primary; Moderate salinity	326.0
	Secondary; Oriented along seams.	183.4
OC-6D	Primary; Gas-rich and halite-bearing.	>350
	Secondary; Oriented along seams.	187.2
	Secondary; Oriented along seams.	183.6

In terms of tectonic setting, the area of the O.K. deposit is less ambiguous. Regional relationships, as discussed by Steven and Morris (1984), indicate that the 28.4 Ma O.K. stock (Lemmon and others, 1973) was intruded prior to the onset of Basin and Range extension. At this time, a broad magmatic arc, related to the subduction of the Farallon plate, was active in Utah (Westra and Keith, 1981). On a more local scale, this arc activity produced the Oligocene to earliest Miocene belt of intrusions, calderas, and related mineral deposits comprising much of the Pioche-Marysvale mineral belt. In general terms, this magmatic activity is of the calc-alkalic (to high-K calc-alkalic) magma series (Westra and Keith, 1981).

Comparison of the O.K. Mine with Porphyry Copper Deposits

Numerous similarities exist between the O.K. deposit and porphyry copper deposits. In terms of tectonic setting, the O.K. deposit conforms to porphyry copper models in that it lies within a presumably subduction-related calc-alkalic magmatic arc. Porphyry copper mineralization of the same general age and setting as the O.K. deposit includes the Bingham Canyon (39-36 Ma) and Silver City stock (31 Ma) near the Tintic district.

Metal contents of porphyry copper deposits may range from molybdenum poor to molybdenum rich. A continuum between molybdenum-rich porphyry copper deposits and molybdenum-rich calc-alkalic stockwork molybdenum deposits was pointed out by Westra and Keith (1981). Westra

and Keith (1981) also note that high molybdenum concentrations in some porphyry copper deposits are typically associated with late magmatic differentiates, as may be the case of the aplite dike at the O.K. deposit. Minor precious metal values may also be associated with porphyry copper deposits. Thus, in terms of metal content, the O.K. deposit conforms to both porphyry copper and calc-alkalic stockwork molybdenum deposit models. No trace element data are available for the O.K. deposit.

Another similarity between the O.K. deposit and porphyry copper deposits is the general similarity of temperature and salinities of magmatic-hydrothermal fluids. Values determined for primary fluid inclusions at the O.K. Mine lie within the range documented for porphyry copper deposits of southwestern North America (Titley and Beane, 1981).

Several important differences, however, exist between the O.K. Mine and porphyry copper deposits. Most striking is the difference in size. The O.K. deposit, and associated alteration zones (excluding the propylitic fringe), measures about 600 feet (183 m) in diameter. Typically, porphyry copper deposits are larger by a factor of 10 (Lowell and Guilbert, 1970).

Another important difference is the alteration and mineralization at the O.K. deposit. In porphyry copper deposit models, cooling of the host intrusive and attendant expulsion of an aqueous phase is responsible for generating the earlier altering and mineralizing fluids. Thus, initially at least, altering solutions are intimately related to the host intrusive. At the O.K. Mine, however, the host quartz monzonite appears to have been a passive host upon which the alteration and mineralization was superimposed.

Three aspects of hydrothermal alteration at the O.K. Mine differ significantly from porphyry copper deposits, including the lack of a potassic zone, presence of a silicic zone, and the lack of pyrite in the phyllic zone. Potassic alteration (characterized by secondary K-feldspar and/or biotite) was either never developed or was destroyed by later phyllic (quartz-sericite) alteration at the O.K. Mine. The destruction of earlier potassic alteration in porphyry copper deposits by the inward migrating phyllic assemblage is believed to be accompanied by the alteration of chalcopyrite to pyrite (Titley and Beane, 1981). Complete absence of potassic alteration and the near absence of pyrite in the phyllic zone suggest that potassic alteration was never developed at the O.K. Mine.

Pyrite is a ubiquitous component (up to 10 percent) of phyllic alteration in porphyry copper deposits. Pyrite formation is generally attributed to the sulfurization of Fe extracted from biotite and is spatially associated with biotite (Beane, 1982). At the O.K. deposit, however, magnitite is intimately associated with biotite. Quantitative electron microprobe data, tabulated in table 2, shows that biotite associated with magnitite has a significantly lower FeO:MgO ratio than isolated biotite grains. This suggests that magnetite was at least partially formed from the Fe content of associated biotite. The preferential formation of magnetite instead of pyrite at the O.K. Mine probably reflects the relatively higher O_2 and lower S_2 fugacities during alteration.

A central silicic zone of alteration is not characteristic of porphyry copper deposits. Breccia pipes associated with

Table 2. FeO and MgO values of biotite grains in sample R-8.6B. The biotite that is spatially associated with magnetite has a significantly lower FeO:MgO ratio suggesting than the magnetite extracted from the biotite as it formed.

Biotite Spatially Associated With Magnetite	Biotite Not Associated With Magnetite	FeO	MgO	FeO/MgO
X		17.16	14.68	1.17
X		16.68	14.86	1.12
X		17.20	15.45	1.11
X		16.69	14.91	1.12
	X	18.34	13.64	1.34
	X	18.10	12.54	1.44
	X	17.66	14.59	1.21
	X	18.75	13.21	1.42

porphyry copper deposits may, however, have a higher quartz content.

Comparison of the O.K. Mine with Stockwork Molybdenum Deposits

Genetic models and classification schemes have recently been developed for stockwork molybdenum deposits (Mutschler and others, 1981; Westra and Keith, 1981). According to this work, deposits can be divided into two very distinctive sets, calc-alkalic (also known as low-fluorine or granodiorite molybdenite systems) and climax-type (also known as alkalic-calcic to alkalic molybdenum stockwork or high-fluorine or granite molybdenite systems) deposits. Comparisons of each of these with the O.K. deposit will be made.

Calc-alkalic stockwork molybdenum deposits—As mentioned above, these deposits are similar to porphyry copper deposits. In fact, it has been suggested (Westra and

Figure 5. Plan and sections of the O.K. Mine.

Keith, 1981) that these deposits are gradational with porphyry copper deposits. For this reason, all similarities and differences between the O.K. Mine and porphyry copper deposits discussed above also apply to this deposit type.

Climax-type molybdenum deposits—Deposits of this type are characterized by strong enrichment of a lithophile element suite including F, Be, Sn, Li, Mo, W, U, and others. Alteration assemblages are zoned outwards from a central silicic zone (coincident with the molybdenum ore shell), through potassic, quartz-sericite, and argillic zones. Mineralization is typically formed at the apex of cupolas above silicic batholiths.

One deposit of this type, the Pine Grove deposit, is known in Utah. The Pine Grove deposit consists of disseminated molybdenum-tungsten mineralizaiton hosted by the 24 Ma Pine Grove pluton and is located approximately 30 miles (48 km) west-southwest of the O.K. Mine. No intrusive rocks of the composition associated with climax-type deposits exist near the O.K. Mine. This, coupled with the apparent absence of fluorite in the O.K. deposit, would seem to rule out the possibility of climax-type mineralization at depth.

Comparison of the O.K. Mine with magmatic-hydrothermal breccia pipe deposits

Breccia bodies have long been recognized as a common feature of porphyry systems, occurring both in mineralized and barren systems. Sillitoe (1985) has recently devised a classification scheme for ore-related breccias and work by Burnham (1979, 1985) provides a genetic model for breccia formation. Magmatic-hydrothermal breccias have been divided into two types: pipes related to intrusions (unmineralized intrusive rocks) and breccias within porphyry-type ore deposits (Sillitoe, 1985). Since the O.K. Mine, as presently understood, cannot be considered a porphyry copper deposit, only the first of these breccia deposit types will be discussed. It should be noted that, in the absence of conclusive evidence, mineralized breccia pipes which appear to be unrelated to porphyry mineralization may, in fact, represent high-level manifestations of porphyry systems. The following description is summarized from Sillitoe (1985).

Magmatic-hydrothermal breccia pipes may occur individually or in clusters and are commonly located in the upper parts of, immediately above, or marginal to plutons or stocks. Pipes are generally circular to oval in cross section with a marked vertical elongation. Sizes and shapes of breccia fragments vary widely. Breccia fragments may be surrounded by variable proportions of rock flour, void space, or hydrothermal cement. Pre-existing structures may or may not control the localization of pipes.

Breccia pipes commonly contain copper mineralization. Molybdenum, tungsten and/or gold may also be economically important. Alteration is very common, especially in mineralized pipes, and consists of replacement and open-space-filling. Sericitization (accompanied by tourmaline) is the most common alteration type with chloritization, silicification, propylitic and K-silicate assemblages being less common. Alteration may either end abruptly at the edge of the pipe or extend up to tens of meters into the host rock. Replacement alteration, followed by open-space filling by gangue and ore
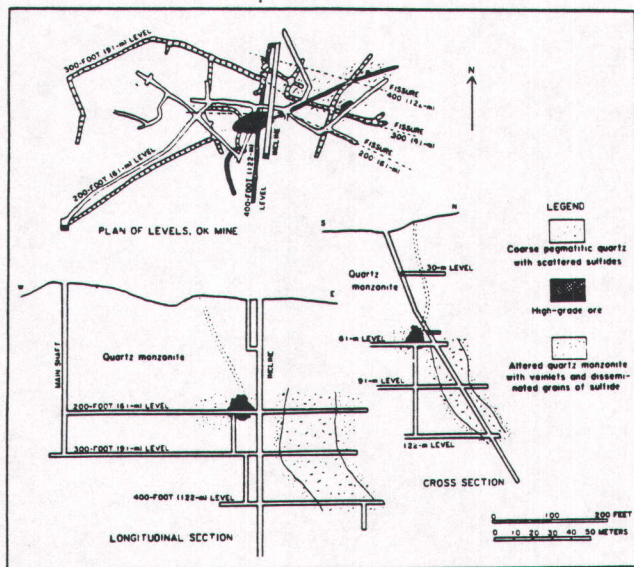
minerals, commonly results in coarse-grained, well crystal-lized, pegmatitic textures. Mineralization is often restricted or of highest grade along the margins of the pipe. Fluid inclusion studies indicate that mineralizing fluids ranged in temperature from 310 to 470°C and in salinity from 1 to 50 equivalent weight percent NaCl.

Although not stated by previous authors, the silicic core at the O.K. Mine may be interpreted to represent a highly silicified breccia pipe. This interpretation is supported by descriptions of brecciation by Butler (1913), Steven and Morris (1904), Morris (1985), and this study, and by the close similarity between the O.K. Mine and the breccia pipe deposit description outlined in the previous two paragraphs. The breccia pipe interpretation has apparently been debated by industry geologists with no clear consensus.

Similarities between the breccia pipe deposit description and the O.K. Mine include size, morphology, mineralization characteristics, host rock, geologic setting, alteration, presence of tourmaline, temperature and salinities of hydrothermal solutions, and coarse texture of gangue minerals. Differences occur only in the degree of hydrothermal alteration. The degree of silicification of the pipe and the extent of wall rock alteration around the pipe appear to be greater than is typical for ore-related breccia pipes.
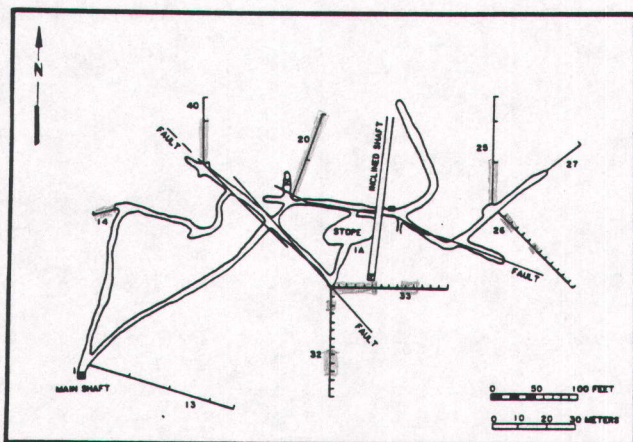

Figure 6. Map of the underground workings at the 200-foot (61-m) level of the O.K. Mine showing sample locations (1 and 1A) and faults.

CONCLUSIONS

Mineralization at the O.K. Mine is tentatively interpreted to be of the breccia pipe-type as described by Sillitoe (1985). Whether or not the pipe is associated with a porphyry Cu-Mo deposit remains to be determined; however, exploration has evidently not resulted in the discovery of such a deposit. It is unknown whether an unexposed intrusion at depth is responsible for pipe formation or if the pipe was formed by fluids expelled from the O.K. stock. Sillitoe (1985) and Burnham (1985) mention an example of a lensoidal quartz mass overlying the apex of a granite cupola at Panasqueira, Portugal (Kelly and Rye, 1979), a feature which may pertain to

the O.K. deposit. Burnham (1985) and Sillitoe (1985) outline a model for ore-bearing breccia pipe formation which may apply to the O.K. deposit. The reader is referred to these papers for further details.

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APPENDIX

Major element analyses of drill cuttings from the 200 foot (61 m) level of the O.K. Mine.

For index map of the sample locations, see Figure 6. The first number of the sample location is the number of the horizontal drill hole form which the sample was taken. The second number is the footage along the hole.

The elements are listed as weight-percent oxide. "LOI" is the Loss On Ignition. This is the loss in weight of the sample on fusion into a glass bead. It is predominantly H_2O with minor amounts of Na, S, and CO_2.

OXIDE   **SAMPLE IDENTIFICATION**

	33-5	33-10	33-20	33-30	33-40	33-50	33-60	33-70	33-80	33-90	33-100	33-110	33-120	33-130	33-140
SiO_2	69.47	67.57	66.06	68.34	65.66	65.54	65.06	64.18	65.13	68.09	67.08	64.10	66.70	65.04	63.97
Al_2O_3	14.17	15.29	14.91	15.18	15.50	15.05	15.33	15.48	15.35	14.80	14.61	15.20	14.75	15.27	14.75
Fe_2O_3	3.41	3.51	4.52	3.90	3.75	4.21	3.72	4.11	4.22	3.48	3.27	3.38	3.87	3.72	5.16
MgO	1.06	1.48	1.49	1.40	1.44	1.39	1.27	1.26	1.31	1.21	1.13	1.26	1.49	1.32	1.32
K_2O	4.88	5.02	4.89	4.62	4.39	4.68	4.46	4.23	4.16	5.35	4.58	4.29	4.03	4.15	4.02
Na_2O	1.73	2.54	2.02	2.22	2.74	2.11	3.21	2.88	2.64	1.69	2.38	2.27	1.80	2.88	2.83
CaO	.42	.46	.40	.51	1.48	.73	2.51	2.44	2.14	1.73	1.75	2.82	1.47	2.26	2.65
TiO_2	.48	.48	.44	.44	.63	.58	.66	.64	.65	.60	.46	.46	.54	.52	.52
P_2O_5	.15	.14	.15	.14	.15	.14	.15	.16	.15	.15	.14	.13	.16	.18	.18
MnO	.03	.03	.03	.03	.03	.02	.06	.04	.04	.02	.04	.04	.02	.04	.04
Cu	.56	.30	.96	.17	.28	.31	.16	.05	.13	.47	.27	.09	.12	.17	.17
LOI	3.96	3.64	3.50	3.51	3.74	3.53	3.52	3.69	3.19	3.18	3.03	3.13	3.22	3.40	3.40
TOTAL	100.32	100.46	99.37	100.46	99.79	98.29	100.11	99.16	99.11	100.77	98.74	97.17	98.17	98.15	99.01

OXIDE SAMPLE IDENTIFICATION

	32-5	32-10	32-20	32-30	32-40	32-50	32-60	32-70	32-80	32-90	32-100	32-110	32-120	32-130	27-5	27-50
SiO_2	65.74	65.86	64.22	65.47	64.68	64.81	64.59	64.14	66.83	64.76	64.20	63.82	63.20	63.81	64.04	63.78
Al_2O_3	15.44	15.29	14.48	15.41	15.32	15.82	15.69	15.53	15.20	15.40	15.56	15.45	15.26	15.32	15.66	15.69
Fe_2O_3	3.60	4.12	6.00	4.66	4.23	3.74	4.05	4.40	3.18	3.95	4.30	4.36	5.97	5.29	4.12	4.32
MgO	1.54	1.54	1.36	1.54	1.37	1.31	1.41	1.46	1.33	1.41	1.53	1.85	1.72	1.64	1.50	1.38
K_2O	4.74	4.63	4.04	4.06	4.01	4.01	4.01	4.14	5.09	3.92	3.95	3.67	3.53	3.66	3.91	4.04
Na_2O	2.81	2.72	2.57	2.66	2.98	2.94	3.33	3.17	2.89	3.36	3.11	3.18	3.26	3.30	3.08	3.16
CaO	.60	.78	1.13	1.47	2.22	2.39	2.85	2.16	1.15	2.33	2.94	3.34	3.55	3.47	2.95	2.96
TiO_2	.50	.51	.46	.54	.53	.48	.50	.53	.48	.56	.57	.61	.58	.59	.52	.50
P_2O_5	.16	.17	.16	.17	.13	.12	.21	.16	.16	.17	.22	.18	.20	.18	.15	.13
MnO	.02	.05	.02	.04	.03	.04	.05	.04	.04	.06	.04	.04	.05	.05	.03	.03
Cu	.10	.08	1.39	.09	.11	.11	.07	.10	.37	.24	.23	.12	.12	.10	.09	.08
LOI	3.98	3.62	3.64	3.68	3.57	3.40	2.94	2.91	2.60	2.14	2.43	2.46	2.49	2.32	3.82	3.28
TOTAL	99.23	99.37	99.47	99.79	99.18	99.17	99.70	98.74	99.32	98.57	99.08	99.08	99.93	99.73	99.87	99.35

OXIDE SAMPLE IDENTIFICATION

	26-5	26-10	26-20	26-30	26-40	26-50	26-60	26-70	26-80	26-90
SiO_2	72.09	66.95	65.12	65.94	67.06	65.60	64.50	65.25	67.11	64.28
Al_2O_3	13.35	15.13	15.66	15.11	14.89	15.20	14.97	14.96	14.83	14.66
Fe_2O_3	1.11	1.86	2.90	3.64	3.91	3.79	4.43	3.62	3.69	3.40
MgO	.26	.46	.85	1.36	1.42	1.42	1.46	1.26	1.39	1.37
K_2O	7.39	9.21	8.58	5.25	4.81	4.69	4.97	4.81	4.52	4.70
Na_2O	.80	.56	1.18	1.95	2.36	2.44	2.18	2.19	1.92	1.94
CaO	.08	.15	.33	1.64	1.10	1.02	.80	1.39	.57	1.57
TiO_2	.60	.55	.56	.52	.73	.50	.72	.49	.47	.57
P_2O_5	.10	.12	.18	.14	.14	.14	.15	.14	.15	.15
MnO	.05	.07	.06	.03	.04	.06	.03	.02	.02	.04
Cu	.07	.51	.66	.15	.15	.09	.30	.09	.07	.08
LOI	4.39	4.48	3.92	3.28	3.08	3.17	3.56	3.88	3.78	4.67
TOTAL	100.29	100.05	100.00	99.01	99.69	98.12	98.07	98.10	98.52	97.43

OXIDE   **SAMPLE IDENTIFICATION**

	26-100	26-110	26-120	26-130	25-5	25-50	25-100	25-130
SiO_2	65.15	64.33	65.07	65.70	68.69	66.63	64.74	63.60
Al_2O_3	14.56	14.93	14.81	14.78	14.74	14.63	15.30	15.10
Fe_2O_3	3.54	3.33	3.44	3.39	2.29	2.91	4.70	4.72
MgO	1.48	1.34	1.49	1.42	.79	.73	1.26	1.25
K_2O	3.84	4.53	4.99	5.11	7.47	6.45	4.39	4.62
Na_2O	1.24	2.38	2.32	1.84	.52	.91	3.13	2.92
CaO	2.90	1.30	1.44	2.36	.33	.30	1.79	1.99
TiO_2	.56	.51	.52	.47	.61	.55	.50	.49
P_2O_5	.17	.14	.14	.13	.17	.13	.14	.15
MnO	.03	.03	.03	.06	.02	.01	.02	.03
Cu	.09	—	—	.09	.74	.86	.05	.12
LOI	4.53	4.38	3.88	4.02	4.23	3.98	3.43	3.03
TOTAL	**98.09**	**97.20**	**98.13**	**99.37**	**100.60**	**98.09**	**99.45**	**98.02**

OXIDE   **SAMPLE IDENTIFICATION**

|	40-10	40-50	20-5	20-50	20-110	14-50	14-30	13-5	13-50	13-100	13-150	13-180	R-9.1	R-8.8B	OC-4	OC-9
SiO_2	69.98	68.34	67.92	66.27	66.74	64.38	64.93	63.66	62.54	63.51	63.02	63.23	71.40	67.56	67.61	66.18
Al_2O_3	13.93	15.36	14.53	14.60	15.36	15.39	15.69	15.77	15.49	15.77	15.43	15.42	13.03	14.71	14.67	14.75
Fe_2O_3	2.01	3.36	2.56	3.88	4.41	4.67	4.99	4.63	4.77	5.25	5.25	5.26	2.29	4.48	4.05	3.98
MgO	.98	1.23	.94	1.36	1.45	1.57	1.70	1.56	1.92	1.75	1.61	1.78	.81	1.50	1.13	1.35
K_2O	6.64	4.52	6.72	4.05	4.48	4.35	4.28	3.84	3.69	3.81	3.75	3.65	6.47	2.88	4.58	4.04
Na_2O	.76	2.54	.50	1.90	2.52	2.54	2.64	3.55	2.61	3.90	3.74	3.70	.29	2.07	3.02	3.39
CaO	.26	.96	.26	1.17	2.30	.75	.73	4.31	4.17	3.62	3.68	3.77	.22	.40	2.06	2.41
TiO_2	.47	.48	.45	.53	.50	.59	.55	.36	.70	.51	.69	.72	.46	.61	.50	.56
P_2O_5	.14	.14	.15	.15	.15	.17	.16	.20	.20	.19	.18	.18	.20	.19	.17	.19
MnO	.01	.02	.02	.03	.04	.03	.03	.04	.04	.04	.04	.04	.02	.01	.03	.03
Cu	.23	.18	.66	.23	.33	.72	.50	.06	.06	.13	.09	.06	—	—	—	—
LOI	3.83	3.39	4.18	3.97	3.19	2.93	2.83	1.85	1.87	1.42	1.65	1.78	4.21	4.06	1.64	1.75
TOTAL	99.24	100.53	98.99	98.14	101.47	98.09	99.03	99.83	98.06	99.90	99.13	99.59	99.40	98.47	99.46	98.63
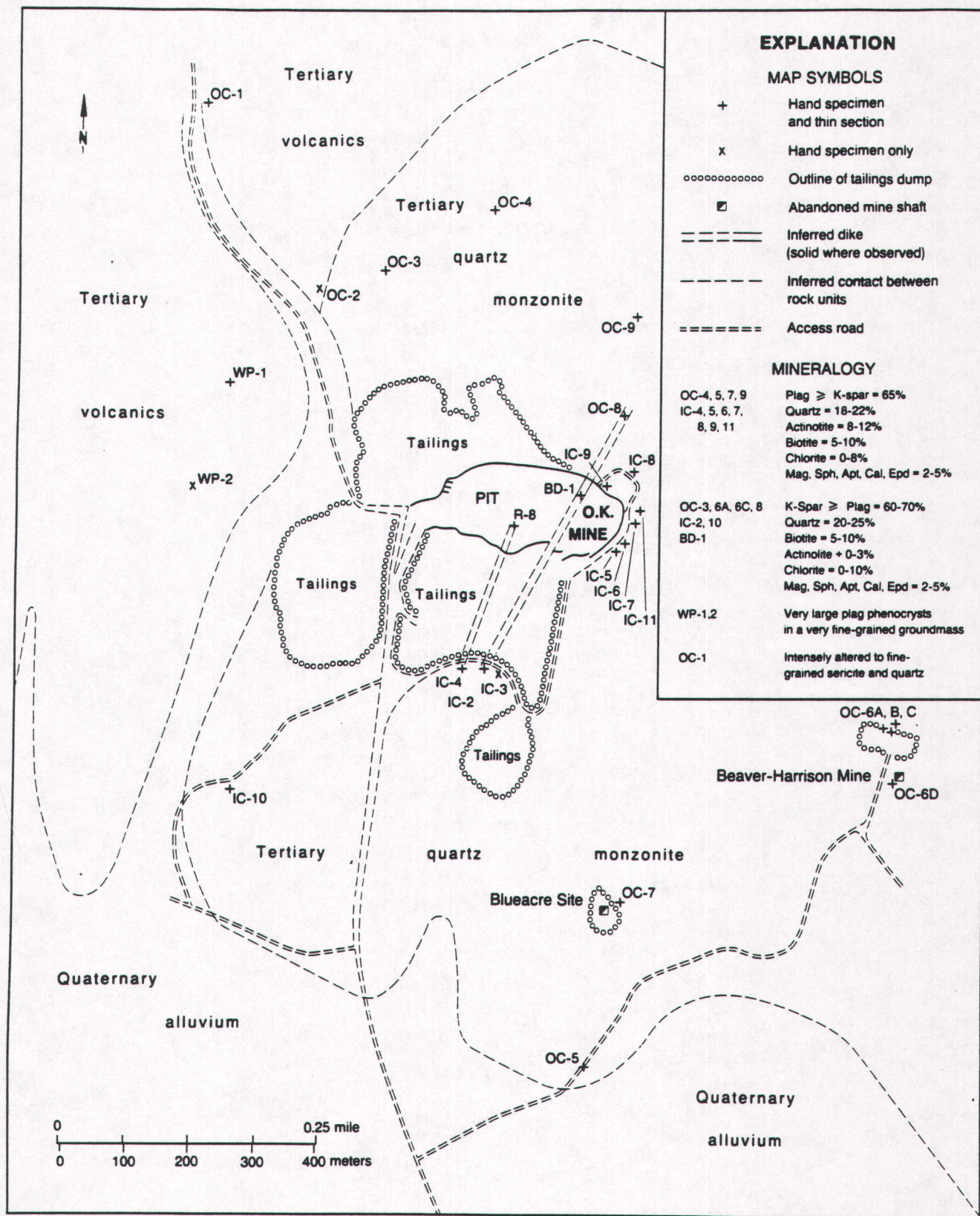
Plate 1. Sample location and geologic sketch map of the O.K. Mine area.